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Effects of Acidity of Simulated Rain and Its Joint Action with Ambient Ozone on Measures of Biomass and Yield in Soybean

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16. ABSTRACT

An experiment was performed to determine whether the presence of ozone modified the effects of acidity of simulated rain on growth and yield of soybean. Beeson, a type II cultivar, was grown in field chambers and exposed to simulated rain at 3 levels of acidity. Each level was applied to plants grown either in unfiltered ambient air or in charcoal filtered ambient air. An interaction between acidity of simulated rain and filtration of ambient air on growth and yield was present. The difference in total dry mass between plants grown in filtered and unfiltered chambers increased with increased acidity, of simulated rain treatments. In filtered air, vegetative mass was only slightly decreased with increased acidity, whereas reproductive mass was increased with increased acidity. In unfiltered air vegetative mass decreased with increased acidity but reproductive mass was only slightly decreased at pH 2.8. Components of yield also were differentially affected by acidity, which indicates the need for a better understanding of the sensitivities of different developmental processes of the plant to each kind of pollutant. The apparent interaction between ozone and acidic rain indicates that further investigations on this combination must be conducted before acidic rain effects on plant growth can be accurately assessed in ambient atmospheres.

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EFFECTS OF ACIDITY OF SIMULATED RAIN AND ITS JOINT ACTION WITH AMBIENT OZONE ON MEASURES OF BIOMASS AND YIELD IN SOYBEAN*

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TROIANO J., COLAVITO L., HELLER L., MCCUNE D. C. and JACOBSON J. S. *Effects of acidity of simulated rain and its joint action with ambient ozone on measures of biomass and yield in soybean.* ENVIRONMENTAL AND EXPERIMENTAL BOTANY **23,** 113–119, 1983.—An experiment was performed to determine whether the presence of ozone modified the effects of acidity of simulated rain on growth and yield of soybean (*Glycine max.* [L.] Merr.). Beeson, a type II cultivar, was grown in field chambers and exposed to simulated rain at 3 levels of acidity, pH 4.0, 3.4 and 2.8. Each level of acidity was applied to plants grown either in unfiltered ambient air or in charcoal filtered (to remove ozone) ambient air. An interaction between acidity of simulated rain and filtration of ambient air on growth and yield was present. The difference in total dry mass between plants grown in filtered and unfiltered chambers increased with increased acidity, of simulated rain treatments. In filtered air, vegetative mass was only slightly decreased with increased acidity, whereas reproductive mass was increased with increased acidity. In unfiltered air vegetative mass decreased with increased acidity but reproductive mass was only slightly decreased at pH 2.8. Components of yield also were differentially affected by acidity, which indicates the need for a better understanding of the sensitivities of different developmental processes of the plant to each kind of pollutant. The apparent interaction between ozone and acidic rain indicates that further investigations on this combination must be conducted before acidic rain effects on plant growth can be accurately assessed in ambient atmospheres.

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INTRODUCTION

ACIDIC precipitation is now perceived as a problem of air pollution owing to its origin in emissions of gaseous oxides of sulfur and nitrogen. As with any other atmospheric pollutant that can directly affect agricultural productivity, the most significant practical problem is in determining exposure–effect relationships because they are the bases for controls, air quality standards and predictions of environmental impact. Field experiments with certain crops have begun to investigate the effects of acidic rain, but many factors can alter the responses of plants to air pollutants and thereby make extrapolation of any set of data to other field investigations problematic.[8] Among these factors are species, cultivar, stage of development of the plant, characteristics of exposure, response variable measured and environmental conditions. The occurrence of

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another air pollutant can be regarded as an environmental factor and a serious problem in the interpretation of results if the joint action of the two pollutants is nonadditive. Recently, IRVING and MILLER[7] reported that exposure to SO_2 appeared to negate increases in seed size caused by acidic rain treatments on soybean (cv. Wells). Although both acidic rain and oxidant occur in much of the north-eastern United States, there has been no report on their combined effects on field-grown plants. The objective of this study, therefore, was to determine whether the response of field-grown soybeans to simulated acidic rain was modified by exposure to different levels of ozone. Soybean plants are known to be susceptible to reductions in yield from exposure to ozone[6] and have been the subject of investigations on the effects of acidic rain.[2,7] Two different levels of atmospheric ozone were obtained by using conventional open-top chambers in which the air supply was either filtered with charcoal to remove ambient ozone or unfiltered. The levels of simulated acidic rain treatments were chosen to determine whether increases in the current acidity of rain that may accompany increased utilization of energy resources would alter plant response to ozone.

MATERIALS AND METHODS

Plant culture

Seeds of 'Beeson', a type II cultivar and 'Williams' a type III cultivar of soybean (Committee for Agricultural Development, Iowa State University, Ames, IA 50011) were sown on 5 June 1978 in six hexagonal plots located in a 20 × 30 m field site in Yonkers, New York. Prior to seeding, the field site was rototilled, raked and fertilized with 10–10–10 (N–P–K) at a rate of 56.7 kg N/ha. Each plot was divided into six equal sectors alternately seeded in a hexagonal lattice design with 'Beeson' and 'Williams'. After emergence, plants were thinned to ten of each cultivar in each sector with 30 cm spacing between plants. One application of 4,4-dichloro-(trichloromethyl)-benzhydrol (Kelthane from Rohm and Haas, Philadelphia, PA 19105) was applied to all plots on 26 July (51 days after seeding) to eradicate an infestation of two-spotted spidermite (*Tetranychus urticae* Koch).

Plants were exposed to ambient ozone (Table 1) and incident rainfall (five events, pH range 3.68–4.83) until 15 July (40 days after seeding) when field chambers[10] were placed over each plot. Each chamber, 2.44 m in diameter and 2.44 m in height, was equipped with a blower that continuously supplied ambient air at 28 m^3/min. Ambient ozone was removed from the air entering three of the chambers with activated charcoal filter assemblies; filter assemblies without charcoal were installed on the remaining three chambers.

In order to exclude ambient rainfall, a clear, plastic tarpaulin was loosely secured over the top of each chamber, which did not restrict the normal outflow of air. Light transmission through the cover was decreased by no more than 25%

Table 1. Summary of ozone concentrations

	Ambient air 10 June–14 July	Unfiltered air chamber 15 July–18 September	Filtered air chamber 15 July–18 September
7 hr av. (11:00–18:00 EST), ppm O_3	0.069	0.027	0.008
24 hr av., ppm O_3	0.036	0.017	0.006
Total dose, ppm O_3–hr	30.1	14.0	4.0
No. of hr > 0.12 ppm O_3*	33	2	0
No. of days 0.12 ppm O_3 was exceeded	9	1	0
No. of hr > 0.08 ppm O_3†	89	16	0
No. of days 0.88 ppm O_3 was exceeded	16	5	0

* Current U.S. ambient air quality secondary standard for ozone.
† Previous U.S. ambient air quality secondary standard for ozone.

and temperatures inside the chambers were not more than 3°C greater than ambient temperatures.

Plants were periodically examined for general vigor, occurrence of foliar lesions and degree of foliar senescence. On 21 September (108 days after seeding), 18 plants of each cultivar in each chamber (6 per sector) were harvested (outer perimeter plants were not harvested); 'Beeson' was at full maturity and 'Williams' was at beginning maturity, (R8 and R7 stage of development, respectively, ref. 3). Because Williams had not attained full maturity, data from this cultivar is not reported. To retain viability and vigor of seed for subsequent tests,[15] entire plants were dried for 3 weeks in a closed greenhouse where temperatures ranged from 25 to 30°C. The number of pods per plant, seeds per pod and weight of seeds were determined. Dry wt of leaves and stems (stalk) and pod hulls of each plant was determined after further drying at 80°C in a forced draft oven for 24 h.

Experimental design and treatment

A 3 × 2 factorial design was used with three simulated rain solutions (pH 4.0, 3.4 and 2.8) and two levels of ozone (charcoal-filtered and unfiltered ambient air). Simulated rain solutions containing a mixture of sulfuric and nitric acids with background concentrations of chloride, calcium and ammonium ions (Table 2), were prepared immediately before use and placed in 19 l. stainless steel pressurized (4.22 kg/cm) containers. Treatments were delivered from the containers through polyethylene tubing (0.64 cm o.d.), to an RD-1 Raindrop Nozzle with a #3 insert (Delavan-Delta, Inc., Lexington, TN 38351) located at the center of each chamber. Each nozzle was situated 1.5 m above ground level, aimed upward, delivered 1.27 cm/hr of simulated rain and covered a 2.0 m diameter circle. Diameters of droplets ranged from 450 to 1720 μm with a median of 730 μm.[11,13] Treatments commenced on 24 July (49 days after seeding; 7 days after the start of flowering) with a total of 22.9 cm of simulated rain deposited by eighteen separate 1 hr events applied over a period of 50 days. Exposures were timed to coincide with overcast or rainy days, but several applications were conducted at dusk due to extended periods of sunshine. The total deposition of hydrogen, sulfate and nitrate ion from simulated rain treatments was 0.2, 10.3 and 5.0 kg/ha, respectively, at pH 4.0, 0.9, 36.4 and 18.0 kg/ha, respectively, at pH 3.4; and 3.6, 140.8, and 70.2 kg/ha, respectively, at pH 2.8.

Ozone (O_3) was monitored in the ambient air and in one filtered and one unfiltered chamber with Monitor Labs Chemiluminescent Ozone Analyzers, Model 8410 (Monitor Labs, Inc., San Diego, CA 93131). Although the data from field chambers were discontinuous, regressions of hourly values from filtered or unfiltered chambers on those of ambient air indicated that the concentrations of ozone were 5 and 60% of ambient air values, respectively. Order statistics that characterize the concentrations of ambient ozone for the entire experimental period are given in a previous publication.[15] Summary statistics, including comparisons to the current and previous U.S. ambient air quality secondary standard for 0_3 are also given in Table 1. For each chamber the pressure difference across the charcoal-filter was measured continuously to indicate whether air

Table 2. Concentrations of principal chemical species in solutions used to generate simulated acidic rain

pH of Solution	Concentration of Sulfate (SO_4^{2-})	Nitrate (NO_3^-)	Chloride (Cl^-)	Ammonium (NH_4^+)	Calcium (Ca^{2+})
	ppm (w/v)				
4.0	4.5	2.2	0.70	0.34	0.40
3.4	15.9	7.9	0.70	0.34	0.40
2.8	61.6	30.7	0.70	0.34	0.40

flow and filter efficiencies remained equivalent throughout the test.

Statistical methods

Data were analyzed by the General Linear Models Procedure of the SAS (Statistical Analysis System, Cary, NC 27511) statistical package. The dry mass of stalk, pod and seed, the number of seeds and pods produced per plant, the number of seeds produced per pod, mass per 100 seeds and mass per 100 pod hulls were analyzed separately by analysis of variance (ANOVA). In the absence of treatment replication, the sector by treatment interaction was used as a test of main effects and their interaction. Use of the sector by treatment variation as the error term was validated by analyzing soybean data (cv. Beeson) from another experiment that was performed simultaneously in adjacent plots with the same chamber design. In that investigation, the respective mean square estimates for replicate plots of the same treatment (5 degrees of freedom) and the treatment by sector term were: 8.5173 and 32.1711 for mass of seeds per plant; 23.0278 and 141.0139 for number of pods per plant; and, 180.3917 and 1008.5000 for number of seeds per plant (R. G. Amudson, personal communication). Consequently, greater variation was associated with the sector by treatment term providing a more conservative test of hypothesis.

Treatment variance for acidity of simulated rain was partitioned into linear and quadratic components.[1] The linear effect was a contrast of the value at pH 4.0 to that at pH 2.8, and quadratic effect was a contrast of the values at pH 4.0 and 2.8 to that at pH 3.4 indicating curvature in response.

RESULTS

No evidence of foliar injury was produced by simulated acidic rain, but symptoms of acute and chronic ozone injury occurred on the foliage of plants grown in all chambers receiving unfiltered ambient air. Bronzing of leaves occurred after periods of elevated ambient ozone concentrations, and symptoms of ozone-induced premature senescence—chlorosis and abscission of basal leaves—became evident during the latter part of August.

Filtration of ambient air significantly affected growth and yield, and there also were significant interactions with the linear effect for simulated acid rain (Tables 3 and 4). Total mass was greater in plants grown in filtered air than in unfiltered air, but the difference between the levels of filtration increased with increased acidity of simulated rain, especially at the pH 2.8 treatment (7.55, 9.01 and 21.23 g at pH 4.0, 3.4 and 2.8, respectively, Table 3). Although a significant interaction of filtration with the linear effect for simulated acidic rain was measured in mass of seeds, the differences in values between filtered air and unfiltered air chambers were less than half that for total mass (0.86, 2.89 and 9.07 g at pH 4.0, 3.4 and 2.8, respectively). Also, differences in total reproductive mass (pod plus seed mass) only approximated one-half the differences in total biomass (1.60, 3.53 and 11.69 g at pH 4.0, 3.4 and 2.8, respectively). Because the effects on reproductive portions do not fully account for the effects on total mass, changes in vegetative mass of stalk must also have been present, though not statistically significant. Thus, in filtered air, reproductive mass increased as acidity of simulated rain increased with only a small concurrent decrease in vegetative mass. In unfiltered air, reproductive mass was decreased only slightly at pH 2.8 with substantial decreases in vegetative mass.

The significant effects of filtration of ambient air on the components of yield indicated that the decrease in mass of seeds in unfiltered air treatments was not caused by changes in the size of individual seeds but in their number. The number of pods produced per plant decreased (overall means of 57 and 49 pods per plant for filtered and unfiltered air treatments, respectively, Tables 3 and 5), which produced a concomitant decrease in the number of seeds per plant (overall means of 117 and 94 seeds per plant for filtered and unfiltered air treatments, respectively). In contrast, both the size of pods and seeds (mass per 100 pods or seeds) and the number of seeds produced per pod were significantly affected by acidity of simulated rain (Tables 3 and 5). The smallest seeds (mass per 100 seeds) were produced at pH 3.4, but this effect was offset by increases in the number of pods and seeds produced per plant (Table 3). The largest seed were produced at pH

Table 3. Effects of acidity of simulated rain and ambient photochemical oxidants on measures of growth and yield of Beeson soybean

Simulated rain at:	pH 4.0		pH 3.4		pH 2.8	
Measurement Applied in:	F†	U†	F	U	F	U
*Dry Mass of**			(g)			
Total above-ground portion	47.94	40.39	45.63	36.62	53.38	32.15
Stalk	27.36	21.27	23.42	17.94	25.72	16.18
Reproductive	20.58	18.90	22.21	18.68	27.66	15.97
Pod hulls						
per plant	5.94	5.13	5.99	4.86	6.95	4.33
per 100 pods	10.63	10.46	9.91	8.95	11.41	9.35
Seeds						
per plant	14.63	13.77	16.21	13.39	20.71	11.64
per 100 seed	13.69	14.44	12.48	12.12	16.27	13.92
Number of			(number)			
Pods per plant	53.3	48.2	57.7	53.1	60.3	44.7
Seeds per plant	101.9	96.9	126.6	104.7	122.8	79.5
Seeds per pod	1.82	1.99	2.13	1.97	1.99	1.70

* Statistical analyses and significant responses as reported in Tables 4 and 5.
† F = filtered air; U = unfiltered air.

2.8 in filtered air, but the number of seed produced per plant was reduced at pH 2.8 in unfiltered air through reductions in the number of pods produced per plant and in the number of seed produced per pod.

DISCUSSION

These results indicate that predictions of the effects of acidic rain on agricultural productivity may be dependent on ozone concentrations. In areas where ozone concentrations are low, acidic rain may stimulate plant growth. Stimulation of growth of other plant species by treatment with simulated acidic rain has been observed in field experiments conducted at sites (Corvallis, OR and Ithaca, NY) where ambient pollutant levels are considered to be low.[9,14] The presence of ozone in this experiment negated potential gains in yield. IRVING and MILLER[7] reported a similar

Table 4. Analyses of variance for the effects of acidity of simulated rain and filtration of ambient air on measures of growth and yield in the Beeson cultivar of soybean

		Mean square* for dry mass† of				
Source of variation	*df*	Total above-ground portion	Stalk	Reproductive portion	Pod hulls	Seeds
Filtration of ambient air	1	4227.8950‡	1341.7988‡	817.6276‡	60.2986‡	463.7123*
Acidity of simulated rain	2					
Linear contrast	1	26.1170	193.7738	80.1657	0.2535	69.5031
Quadratic contrast	1	102.6744	83.9302	0.6329	0.3995	2.0806
Filtration × Acidity	2					
Filtration × Linear	1	804.8206	51.9234	430.1741	13.9699	291.3656*
Filtration × Quadratic	1	166.4847	31.5182	57.1320	1.9293	26.0474
Error	12	248.7541	51.7135	103.3435	6.1326	62.7785

* Calculated F-values significant at the 0.05 or 0.01 levels of probability are denoted by * or ‡, respectively.
† Dry mass for each portion was measured on a per plant basis.

Table 5. Analyses of variance for the effects of acidity of simulated rain and filtration of ambient air on measures of components of yield in the Beeson cultivar of soybean

Source of variation	*df*	Mean square* for ‡ # of pods per plant	Mass per 100 pod hulls	# of seeds per plant	Mass per 100 seeds	# of seeds per pod
Filtration of ambient air	1	1811.1154*	31.0082‡	14164.3925*	14.3478	0.2476
Acidity of simulated rain	2					
Linear contrast	1	49.9614	0.2377	57.7896	25.5479	0.0622
Quadratic contrast	1	363.6375	22.9368‡	5677.4497	107.7410‡	0.7513
Filtration × Acidity	2					
Filtration × Linear	1	483.3180	15.0740*	6323.1616	34.1566*	0.9169*
Filtration × Quadratic	1	192.6210	0.1462	25.2843	1.9579	0.0693
Error	12	389.5765	2.3104	2382.3032	6.6924	0.1878

* Calculated *F*-values significant at the 0.05 or 0.01 levels of probability are denoted by * or ‡, respectively. Components of yield were measured on a per plant basis.

result whereby potential stimulation of yield in soybean by simulated acidic rain treatments was negated by the presence of SO_2. Apparently, the effects of acidic rain are modified by additional stress factors. The reduction in yield of field-grown soybeans by simulated acidic rain reported by Evans *et al.*,[2] could have resulted from an interaction of simulated acidic rain treatments with elevated concentration of ambient air pollutants at that location. It seems necessary to measure and report the concentrations of other air pollutants when performing field experiments with simulated acidic rain.

Partitioning of dry matter between vegetative and reproductive portions of the plants was affected differently by simulated acidic rain treatments depending on the level of ozone. In filtered air, a greater effect of acidity was measured in the reproductive portion, especially in seed mass, than in stalk mass indicating increased allocation of photosynthate to reproductive portions with increase in acidity of simulated rain. However, in unfiltered air, greater changes in stalk mass were measured with increased acidity of simulated rain. This effect may have been due to an enhancement of the premature senescence and abscission of leaves caused by ozone in the unfiltered chambers. Components of yield, especially seed size, were also differentially affected by acidity of simulated rain indicating that sensitivity of each component of biomass and yield to exposures of acidic precipitation both within and between levels of filtration needs to be determined.

The results of this investigation may also have agronomic implications. The stimulation of plant growth by increased acidity of simulated rain suggests that low concentrations of nitrate, sulfate, or hydrogen ions may act as foliar nutrients, especially when applied repeatedly. Additional information on the effects of concentration, acidity, and timing of these applications might provide some insight into the manipulation of these processes for increased crop production.[5] This investigation also indicates that apparent differences in results obtained from field investigations on the effects of foliar fertilization on growth and yield of soybean[4,12] might be related to temporal and spatial fluctuations of wet and dry deposition of ambient pollutants.

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REFERENCES

1. Cox D. R. (1958) Pages 91–133 *in Planning of experiments*, John Wiley and Sons, New York.
2. Evans L. S., Conway C. A. and Lewin K. F. (1981) Yield responses of field-grown soybeans exposed to simulated acid rain. Pages 162–163 *in Proc. Int. Conf. Ecol. Impact of Acid Precip., Norway, SNSF Project.*

3. Fehr W. R. and Caviness C. E. (1977) Stages of soybean development. *Iowa Agric. Home Econ. Exp. Stn, Spec. Rep.* **80,** 1–12.
4. Garcia R. L. and Hanway J. J. (1976) Foliar fertilization of soybeans during the seed-filling period. *Agronomy J.* **68,** 653–657.
5. Gay S., Egli D. B. and Reicosky D. A. (1980) Physiological aspects of yield improvement in soybeans. *Agronomy J.* **72,** 387–391.
6. Heggestad H. E., Howell R. K and Bennett J. H. (1977) The effects of oxidant air pollutants on soybeans, snap beans, and potatoes. *U.S. Environ. Prot. Agency. Ecol. Res. Ser.* EPA 600/3–77–128.
7. Irving P. M. and Miller J. E. (1981) Productivity of field-grown soybeans exposed to acid rain and sulfur dioxide alone and in combination. *J. environ. Qual.* **10,** 473–478.
8. Jacobson J. S. (1980) The influence of rainfall composition on the yield and quality of agricultural crops. Pages 41–46 *in Proc. Int. Conf. Ecol. Impact Acid Precip., Norway, SNSF Project.*
9. Lee J. J., Neely G. E., Perrigan S. C and Grothaus L. C. (1981) Effect of simulated sulfuric acid rain on yield, growth, and foliar injury of several crops. *Env. Exp. Bot.* **21,** 171–185.
10. Mandl R. H., Weinstein L. H, McCune D. C. and Keveny M. (1973) A cylindrical, open-top chamber for the exposure of plants to air pollutants in the field. *J. envir. Qual.* **2,** 371–376.
11. Overcamp T. J., Israel G. W. and Pringle W. J. B. (1976) Drift droplet deposition measurements from a brackish-water natural draft cooling tower. Pages 586–592 *in Symp. Atmos. Turbul., Diffus., Air Qual.*, 1976.
12. Sesay A. and Shibles R. (1980) Mineral depletion and leaf senescence in soya bean as influenced by foliar nutrient application during seed filling. *Ann. Bot.* **45,** 47–55.
13. Stainer R. D. and Stowe C. D. (1979) Direct methods for measurement of small water drops. *N.Z. J. Sci.* **19,** 135–143.
14. Troiano J., Heller L. and Jacobson J. S. (1982) Effect of added water and acidity of simulated rain on growth of field-grown radish. *Environ. Pollut. (Series A)* **29,** 1–11.
15. Troiano J., Colavito L., Heller L. and McCune D. C. (1983) Observations on the viability of seed harvested from two soybean cultivars exposed to acidic simulated rain and photochemical oxidants. *Agric. Environ.* (in press).

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